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TECHNICAL TRANSLATION

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SPACE TECHNOLOGY STUDIES PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON June 1963

National Center for Space Studies

Scientific and Technical Directorate

SPACE TECHNOLOGY STUDIES PROGRAM

Technical Programs Committee Report

1963-1965

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*CNES — Centre National d'Études Spatiales (National Center for Space Studies).

INTRODUCTION

The National Center for Space Studies has, from its inception, faced a double task. First, it was necessary to continue the on-board rocket tests which had already been started under the sponsorship of the Space Research Committee, and to perfect these tests quickly in order to construct simple scientific satellites compatible with the DIAMANT launcher. Secondly, future missions had to be prepared too — and these are necessarily of a very delicate nature — in order to perform significant experiments in the context of the technical progress which can be foreseen for the years 1965-1970. The technical studies program presented here was prepared in this spirit, in support of the scientific missions program.

For a short period of time CNES is concentrating all its efforts on the construction of lightweight satellites — of 80 kg nominal weight — and on the installation of ground station and computer systems for scientific information acquisition and analysis. To fulfill this task it seems necessary to improve the present capabilities of French industry, further, toward lighter weights and increased operational reliability. For this first generation of satellites we can only refine existing equipment. The exploration of new or not well proved solutions has therefore been excluded. Only standard techniques have been chosen, such as those of solar cells for power supplies, frequency modulation communication systems for telemetry, and an interference device similar to the American Minitrack system for radio positioning, thus obtaining operational equipment of very good quality in minimum time and without any additional technological studies. With this in mind, a certain number of short-term studies are mentioned in this report, particularly the development of solar cells and batteries for space environment conditions, the study of a magnetic tape recorder, and the construction of photoemissive tubes.

After this first generation of satellites, the goal of the space program is the completion of powerful launchers. To use these rockets suitably and to participate effectively in research which will then have made considerable worldwide progress with respect to presently conducted experiments, CNES must be prepared to undertake scientifically ambitious and technically very delicate missions. Objectives selected are therefore ambitious with respect to the present state of technology, but they correspond to the technological level that must be expected in a few years. This research orientation should allow the nation's industry to acquire the experience required so that missions compatible with the advancement in world capabilities can be undertaken in the 1965-70 period. This choice has led CNES to start essentially long-term studies in vanguard techniques, rejecting certain easier short-term developments. With this in mind, a choice has been made to go from photovoltaic cells of a few tens of watts to the construction of an on-board nuclear reactor of several tens of kilowatts, rejecting intermediate power sources such as radioisotope sources or solar concentrators. In the field of communications, it is proposed to study digital coding systems and on-board data reduction systems right now, in order to develop distant links with space probes. In the field of piloting and servo-mechanisms, attitude stabilization systems will be studied that will permit effective earth atmosphere observations and complex space flight maneuvers.

This technical development program would only be a balanced one if it rested on a very marked improvement in the components or parts making up the systems we have just described. Mindful of the considerable effort already under way nationally in fields like propulsion, materials, and electronic components, this report only mentions the complementary studies which are necessary for the adaptation to space applications of results obtained elsewhere.

It is essential, however, to realize that it is this basic knowledge of new materials and generally very high quality components that will eventually determine long-term French technological capabilities. It is therefore essential that CNES contribute a fair share to the study of these basic techniques, of which it will be one of the principal beneficiaries.

Letter from Mr. J. Voge

Chairman of the CNES
Technical Programs
Committee

The attached report was prepared by the CNES Technical Programs Committee, in accordance with the authority conferred upon it by the Board of Directors. In agreement with the Directors of CNES, the Committee intends to establish a 3-year (1963-65) national space technology studies program, such as to coincide with the execution of the 4th Development Plan. The studies which were accepted are those which will enable us to construct our future spacecraft with essentially French material and will also put the French industry in a good position vis-à-vis the European space industries. These studies must therefore be considered as absolutely necessary.

One of the tasks of the Committee has been to avoid duplication with the programs of other civilian organizations (CEA,* CNET,**, DGRST***) and especially with military programs (Department of Vehicles of the Ministerial Delegation for Armament, DRME****), parts of which are of direct space interest and could be used by CNES. Thus we have tried to draw up a unified national program, referring repeatedly to the studies being carried out by these various organizations. It was also thought that some of the studies proposed in this report could be left to organizations other than CNES, under a plan of coordinated action. It would be possible, for example, to assign development of an on-board nuclear reactor to CEA. Organizations such as DRME, ONERA,***** and CNET might possibly play an analogous role in other parts of the program, considering their technical potential and their own experience. It is essential, in particular, that contracts awarded to industry be carefully drawn up and supervised in all phases of their execution.

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*Commissariat à l'Energie Atomique; Atomic Energy Commission.

**Centre National d'Etudes des Télécommunications; National Center for Communications Studies.

***Délégation Générale à la Recherche Scientifique et Technique, General Delegation for Scientific and Technical Research.

****Direction des Recherches et Moyens d'Essais; Directorate of Research and Testing.

*****Office National d'Etudes et de Recherches Aéronautiques; National Bureau for Aeronautical Studies and Research.

As chairman of the Technical Programs Committee, I must, after these few general remarks, thank all the members of the Committee for their effective and rapid action, and especially those who consented to chair one of the six groups of experts which were formed and which brought together the best French specialists from industry as well as from the Government. These groups were able, in less than three months, to furnish us not only with the bases needed for the elaboration of this program, but also with much more detailed papers which will be extremely useful when specific projects are established. All those who participated in this task deserve congratulations and thanks. I would like to mention separately the Committee Secretary, Mr. Pierre Morel, who prepared the synthesis constituting this report, before its final discussion, from data furnished him by the groups of experts.

Paris, 18 February 1963

Note: This report was approved by the Board of Directors of CNES on 23 February 1963.

THE CNES TECHNICAL PROGRAMS COMMITTEE

1. FUNCTIONS

The Technical Programs Committee of the National Center for Space Studies was created 1 June 1962 by decision of the CNES Board of Directors. Its functions are to:

- draw up the list of technical studies and research of interest to the space field, in agreement with the General Delegation for Scientific and Technical Research,
- determine the priority courses with respect to national, international, and foreign programs,
- calculate the funds needed,
- propose a national program,
- establish the programs to be proposed to international organizations,
- suggest the distribution of responsibilities and work, according to competence and funds.

2. LIST OF MEMBERS

Jean-Jacques BARON	Director, Atomic Applications, Special Metals and Electrothermal Products Division, Compagnie des Produits Chimiques et Electrométallurgiques Péchiney (Péchiney Chemical and Electrometallurgical Products Co.). Head of the Materials and Structures Group.
Roger BETEILLE	Chief Engineer, Studies Director, Technical Group of Cannes, Sud-Aviation Co. Head of the Environmental Standards and Tests Group.
Edouard BILLON	Chief Engineer First Class of the Air Force, Assistant Director, Technical

Research, Directorate of Research and Testing, Ministerial Delegation for Armament (DMA). Head of the Propulsion Group.

Jacques BLAMONT	Scientific and Technical Director, National Center for Space Studies (CNES), Director, Aeronomy Branch, National Center for Scientific Research (CNRS).
Jean-Pierre CAUSSE	Chief, Satellite Division, Scientific and Technical Directorate, National Center for Space Studies (CNES).
Daniel CHAMOUTON	Chief Engineer First Class of the Air Force, Assistant General Director of the Société Française d'Equipement pour la Navigation Aérienne (SFENA) (French Air Navigation Equipment Company). Head of the Stability and Guidance Group.
Christian FAYARD	Communications Engineer, in Charge of the Remote Control Department, National Center for Communications Studies (CNET). Head of the Communications Group.
André GAUVENET	Executive Secretary to the Atomic Energy High Commissioner. Head of the Power Plants Group.
Jean KOVALEVSKY	Astronomer, Central Astronomical Office. Head of the Satellite Applications Group.
Pierre MOREL	Chief, Programs Division, Scientific and Technical Directorate, National Center for Space Studies (CNES). Secretary of the Committee.
Paul MULLER	Titular Astronomer, Chief, Satellite Branch, Paris-Meudon Observatory. Head of the Optical Methods Group.
Jean-Claude SIMON	Director, Space Studies Group and Applied Physics Department, Compagnie Générale de Télégraphie sans Fil (General Wireless Co.). Head of the Data Processing, Memory and Components Groups.

Pierre SOUFFLET	Chief Engineer First Class of the Air Force, Director, Vehicle Department, Ministerial Delegation for Armament (DMA).
Jean VOGE	Chief Communications Engineer, National Center for Communications Studies (CNET), Member, National Committee for Scientific Research. Chairman of the Committee.
Philippe WACRENIER	Engineer, Assistant to the Chief, Development Plans Branch, General Delegation for Scientific and Technical Research (DGRST).

Note: The members of the CNES Board of Directors may attend the Committee sessions.

SPACE TECHNOLOGY STUDIES PROGRAM

I

PROPULSION

There are three kinds of spacecraft propulsion:

- Chemical propulsion,
- Electrical propulsion,
- Nuclear propulsion.

In addition, nonstandard launch systems are considered which do not fall into the above-mentioned categories.

I.1. CHEMICAL PROPULSION

It immediately and obviously appears that French and European space programs are first of all limited by the capability of the available launch vehicles or, which is the same thing, by the propellant thrust. Since these vehicles must, in the foreseeable future, be based upon chemical propulsion, it becomes absolutely essential to the normal development of space flight programs to devote heavy technological effort to the perfecting of chemical propellant rockets, and more particularly to develop high-thrust engines utilizing highly energetic propellants such as the liquid hydrogen-liquid oxygen pair.

A considerable effort has been begun by the Ministerial Delegation for Armament in order to develop hydrogen and oxygen cryogenic propellant propulsion, within the framework of development of the DIAMANT (national program) and CECLES*/ELDO (European program) second generation launch vehicles. This effort is essentially comprised of basic studies for the time being, but is about to take material

*Organisation Européenne pour la mise au point et la Construction de Lanceurs d'Engins Spatiaux; European Organization for the Perfection and Construction of Spacecraft Launchers.

form through the construction of a booster stage prototype (DIAMANT H_2-O_2 third stage). This program of perfecting advanced boosters is financially supported by the Ministerial Delegation for Armament because of its probable military applications. The study of hydrogen-oxygen propulsion is not considered in this report, in spite of the essential interest that these high performance propellants hold for space missions.

Assuming, then, that the study of liquid hydrogen and liquid oxygen rocket engines and the construction of second generation chemical propulsion booster prototypes are pursued independently of the CNES budget, we need only consider certain complementary studies of special concern to satellite equipment and space probes: auxiliary boosters for trajectory correction. From this standpoint, particular attention must be paid to propellants which can be stored in space environment conditions, and to ultralight tank structures (spherical booster).

I.2. ELECTRICAL PROPULSION

Electrical propulsion is undeniably the most promising solution we can presently envisage for very ambitious missions of long duration, such as the transfer from Earth orbit to Mars orbit. Thanks to the very high specific impulse of this mode of propulsion the ejected propellant mass is low. On the other hand, the power consumption is very high, so that any electrical propulsion project is literally held up by the construction of a nuclear reactor capable of feeding it (approximate power of 100 kw, electrical).

The present state of technology in this field is characterized by the abundance of a great variety of solutions from among which it is impossible to make a firm choice: nothing warrants a statement that one or another type of electrical propulsion engine will be retained in a few years because of a marked superiority for a certain class of mission.

Various types of electrical propulsion engines are already under study by the CEA (within the framework of work on dense plasmas), by the ONERA, and by industrial laboratories. Under these circumstances, immediate acceleration of the research effort in the field of electrical propulsion does not appear necessary to the Committee. The Committee therefore recommends concerted action joining all organizations interested in electrical propulsion. The Committee also recommends that CNES organize a colloquium on electrical propulsion where all the various groups active in this field might present the results of their work and future prospects.

I.3. NUCLEAR PROPULSION

Although the projects which can be envisaged are necessarily very distant, this technique is so interesting that at least detailed preliminary studies should be undertaken which would permit a correct estimate of the difficulties and possibilities.

Considering missions capable of being carried out by nuclear propulsion vehicles, two avenues of research are apparent. The usual idea is to see in thermonuclear propulsion a means for improving the performance of the first launcher stages. Compared with chemical rockets, the specific impulse is doubled by using as propellant mass hydrogen heated to a fairly high temperature. The expected advantage is tempered, however, to a degree which should be clearly defined by the dead weight of the propulsion reactor. This system has taken shape in the United States in the ROVER project.

Secondly, a nuclear rocket could be constructed that would operate for a sufficiently long time with an average thrust of the order of a few tens of kilograms, with a high specific impulse (at least 700 seconds). Such an engine would permit launch to planets from low earth orbits. We should emphasize that the U.S. Air Force seems to be following these lines, which will probably lead to more compact solutions than ROVER.

The Committee has recognized the vast future possibilities of thermonuclear propulsion, and also the considerable magnitude that a thermonuclear propulsion reactor development program would probably involve (perhaps exceeding our national capabilities). This Committee therefore recommends the priority undertaking of an orientation study to explore the difficulties that must be surmounted, to evaluate the cost and the duration of a development program, and to estimate the performance to be expected from a nuclear propulsion reactor. It seems urgent, indeed, that all the elements for judging nuclear propulsion should be assembled particularly in order to have clear ideas as far as international proceedings are concerned.

I.4. NONSTANDARD LAUNCH MEANS

A great variety of launch means has been examined, and none seems to justify immediate financing. The Committee therefore recommends keeping abreast of possible foreign solutions and up with the literature.

II

MATERIALS AND STRUCTURES

The only studies which have been considered are based on the orbital flight conditions briefly indicated below:

- vacuum ($<10^{-9}$ torr),
- temperature: an arbitrary range has been selected, from -60°C to +200°C, corresponding to the thermal cyclic variations of a low satellite,
- ionizing radiations: dangerous flux for some sensitive elements such as solar cells,
- meteorites: the effect of surface erosion can influence the thermal balance or destroy transparency. Experimental study of this erosion, unfortunately very difficult, has been undertaken by DRME.
- ultraviolet light: deterioration of certain coatings. For these materials studies it will be necessary to construct combined environmental chambers (vacuum, temperature, light rays), complicated but small in size, capable of operating a long time without interruption.

Below are enumerated the various materials studies which are necessary to insure in a fairly short time a reliable and long-time operation of the mechanical parts and structure of advanced satellites (especially satellites having moving parts).

This program specifically relates to certain special materials used in satellites and must be understood as complementary to the very important materials studies being undertaken elsewhere.

Materials Studies:

1. Mechanical properties of metals and alloys under the effects of vacuum and temperature (structural materials, electrical contacts, tight joints).

2. Properties of plastic materials under the effects of vacuum and temperature.

3. Materials transparent to electromagnetic waves (optical materials).

4. Absorbent and emissive coatings.

5. Friction and lubrication of metals and plastic materials in vacuum (10^{-7} to 10^{-10} torr).

6. Behavior under radiation.

III

POWER PLANTS

All the processes leading to the supply of power needed for the operation of satellites and space probes will be discussed in this chapter. This power will very probably be taken either from sun rays or from nuclear energy.

Power Plant Needs:

The power necessary for the operation of a spacecraft cannot be accurately determined without knowing exactly the nature of the on-board equipment, the type and duration of the mission, and the weight of the payload. Orders of magnitude can be derived, however, for the needed amounts of power. Power ranging from a few watts to a few tens of watts appears adequate for the usual scientific experiment. The use of electric propulsion systems requires a minimum of 2 kilowatts. The transmitter and ancillary equipment of a radio broadcast stationary satellite would require 50 to 100 kilowatts. Much less power would be required by a communications satellite (stationary or not). In any case it is essential to devote a great deal of attention to the construction of these power sources, because the experience of American programs shows that the useful life of space missions is most often limited by the length of proper supply source operation. It is therefore necessary to make this source as resistant as possible to environmental conditions (shock, vibration, radiation, meteorites, etc.). The gamut of possible means to achieve this is sufficiently wide for an ancillary power source, adapted to the planned mission, to be conceived of in any case. Budget limitations, however, forbid construction of all the possible systems, and consequently it is necessary to emphasize the limitations that the absence of such sources would impose on the space program.

Radioactive element sources could become necessary for missions requiring either exceptionally long duration or special endurance and stability characteristics (for example, in radiation belts).

Except for these very special missions, however, radioactive element sources do not seem to offer advantages which would justify fairly costly development for space applications.

This is not the case as far as the on-board reactor is concerned, because abandoning the fission power source would essentially mean giving up all missions requiring power exceeding a few kilowatts. This rejection would seriously limit the prospects offered by electrical propulsion systems for distant space missions. The exploration of distant planets absolutely requires adequate power sources to supply experiments which are necessarily quite complicated, and to permit retransmission of data to earth at a sufficient rate (a radio transmitter of a few kilowatts is necessary). Under these conditions the on-board nuclear reactor seems to be essential to a long-term space program. To reject this power source, which is unique because of its performance, would mean long-term prevention of access to distant planets and interstellar space.

To summarize, a space power source development program must include the following:

- studies for early application essentially involving the adaptation to space flight conditions of source elements already existing for earth applications: electrochemical batteries, solar cells;

- long-term studies of average power sources (advanced solar cells) and high-power sources (nuclear reactors). Because of the very long time that must be anticipated before reactor studies are completed, it is essential to start preliminary studies as soon as possible, so that no precious time is lost.

III.1. ELECTROCHEMICAL BATTERIES

We shall not consider nonrechargeable batteries, which are suitable for very short missions (manned flight). Among the various types of rechargeable batteries, sealed nickel-cadmium cells are the most interesting. Nickel-cadmium cells are relatively heavy (since their total capacity is only 30 watt-hours/kg) but very reliable, provided the charge-discharge cycle is well adjusted. A lifetime of several thousand cycles is possible if the discharge depth does not exceed 20% of the total capacity. This type of battery is now available in France in sealed cartridges and only minor adjustment would be required to adapt them to space conditions. This adjustment involves the following:

- studies of battery structures as a function of charge-discharge cycles in connection with solar batteries;

- studies of tightness in space conditions.

In the future, the nickel-cadmium battery could be replaced by the silver-cadmium battery which has double the power per kg, provided the life problem can be solved. For short missions having very limited recharge capabilities the silver-zinc battery has considerably high power per kg (165 watt-hours/kg). Only tightness in space conditions must be studied, similar to the nickel-cadmium battery.

One of the most attractive approaches for improving the specific capacity of electrochemical cells is that of gas (oxygen-hydrogen) or metal (oxygen-alkaline metal) fuels. Today, cells are made for earth applications which have a capacity of 650 watt-hours/kg, and improvements are well in sight. However, the very serious problems raised by the practical application of fuel cells to space missions have not really been attacked yet.

These technological problems are the following:

- to obtain a fair lifetime of several thousand hours,
- operation in weightless conditions,
- effects of ionizing radiations.

It would be desirable to participate in orientation of the concerted action in this field which is led by the General Delegation for Scientific and Technical Research, so that possible space application of these cells may be kept in mind.

III.2. SOLAR CELLS

The photovoltaic conversion of solar energy used in the satellites already launched is quite suitable for first generation spacecraft (from a few watts to several tens of watts of power). This conversion system essentially uses silicon cells which are already going into production in France.

When associated with a nickel-cadmium battery these cells have a total power per kg ranging between 1 and 16 watts, depending on satellite and orbit characteristics. The over-all mean efficiency (protection included) is about 6-8%. Unfortunately there is a great deal of leakage in the manufacturing process. By selecting the cells it might be possible to obtain higher efficiencies and consequently improved total power per kg. The technology of silicon cells is already sufficiently advanced in France so that they will be available shortly. There are, however, studies to be done in order to adapt them to space, as follows:

- choice of coating to achieve proper thermal balance,
- protection against radiation,
- study of resistance to thermal shock,
- mounting on the satellite structure,
- electrical and thermal connection studies,
- decrease in loss of the electrical characteristics.

Various improvements in photovoltaic conversion are to be expected, especially with the development of gallium arsenide cells. Thin film cells are under study without any idea yet as to their future performance. This research may eventually replace the technological study of silicon cells.

Other solar energy conversion processes have also been taken into consideration:

- thermoelectric conversion,
- thermoionic conversion,
- thermodynamic conversion.

The thermoelements are much less sensitive to radiation than photovoltaic cells but their power efficiency is markedly less, which is a serious drawback as far as first generation satellites are concerned, since these are small in size. As far as the other two methods are concerned, they require a mirror-type focus permanently oriented toward the sun, which limits their usage possibilities considerably. We shall come back to this point in connection with the nuclear reactor program.

III.3. ON-BOARD NUCLEAR REACTOR

It is likely that such a project, started on a national scale, could be taken over by CERS*/ESRO and financed on a European scale. It is therefore desirable to start preliminary studies as soon as possible in order to take the lead in this project.

Because of the technical difficulties already apparent, we think development of an on-board reactor will take a long time. It is particularly impossible in a short time to make the basic technical choices which come to mind:

- neutron source: fast or moderate reactor,
- choice of fuel: U or Pu,
- choice of fluid for the thermal cycle: Na, Li, Hg,
- choice of conversion system: thermodynamic or static.

At most we can state that from our present knowledge uranium poses fewer problems than plutonium. The fast neutron type would require heavier fuel investment than the moderated neutron type.

*Organisation Européenne de Recherches Spatiales; European Organization for Space Research.

Thermodynamic conversion seems nearer than direct conversion. Deciding on certain features too soon would mean imitating the American programs, without hope of avoiding certain disadvantages already apparent in the choices made for SNAP (Systems for Nuclear Auxiliary Power).

A period of examination and experimental studies of 2 to 3 years will, however, permit a good choice based upon results of studies where new technologies would be explored in which France is effectively in the forefront:

- use of Pu as fuel,
- use of direct conversion.

This exploratory period is not simply a period of reflection. It will require:

- literature surveys and conception studies,
- technological attempts on basic problems which are common to all types of reactors or which are part of the most probable choices: high temperature liquid metal cycles (including boiling studies);
- studies on radiators, turbines, alternators,
- studies on static conversion systems.

The first years correspond to subassembly construction (such as thermal cycles, critical assemblies). Preliminary design of a ground prototype, involving the making of essential choices, would come about in the third year of the studies. The construction and test phase of the ground prototype would last 4 to 5 years, so that a prototype of this sort could be ready in 7 or 8 years after the start of the program. The construction of a hot critical assembly seems necessary in the exploratory period, probably in the second or third year of the program. This assembly would, of course, use a fairly large amount of fuel, plutonium or enriched uranium.

To sum up, the proposed program would be the following:

- exploratory period (2 to 3 years)

	• over-all studies
	• general technological studies
Studies	• studies of elements already conceived (and in part common to several power systems)
	• evaluation of static conversion systems (reactor tests).
	• hot critical assemblies
Construction	• cycles
	• prototypes of radiators, turbines, etc.

- at the end of the exploratory period:
    - selection period
    - preliminary design
- construction period (to be defined).

It would be reasonable to devote great attention to advanced methods of thermal energy conversion in a program of such importance, because any improvement in the conversion efficiency would entail very marked improvement in system performance (where unconverted heat must be dissipated by radiation). Therefore great effort will be devoted to the study of turbomachines and static converters (thermoionic).

A suitable choice of thermodynamic cycle and fluids would permit reaching a solution befitting both nuclear reactor and solar energy conversion. Thus it would be very useful to build a satellite with sun focus and turbomachine which would be a test vehicle for the thermodynamic conversion system under real conditions.

Because of the major importance of the power source for future space missions and because of the very long delay in making an on-board nuclear reactor, the Committee recommends top priority starting of the study for this source. The Committee also suggests entrusting direction of this program to CEA.

IV

OPTICAL AND SCIENTIFIC INSTRUMENTS

IV.1. OPTICAL INSTRUMENTS

The optical instruments presently utilized for space vehicle optical tracking are, essentially, theodolites and long focal length cameras. The two projects mentioned below are especially attractive since they could be carried out at low cost and since they would also show the competence of the French optical industry.

Theodolite Recorder Project:

The Meudon Observatory has developed a 70 mm aperture tracking theodolite (ASTRO 1) for the artificial satellite observation program, 10 of these instruments having already been constructed. The use of this theodolite, however, requires a trained observer capable of simultaneously reading the graduated circle and observing the passage of the satellite. It would be extremely useful to develop, from this device, an all-purpose theodolite of high class equipped with an automatic recorder recording time and the elevation and azimuth angles.

The device comprises a reference disk on which 10,000 radial lines are traced, the latter being spaced by white strips of the same width. An electronic counter puts the disk rotation into digital form. Since it is possible to count the black-white and white-black passes, a precision of two hundredths of a degree is achieved.

200 x 600 Camera Project:

The long experience of optical tracking stations shows that a 600 mm focal length camera would give optimum results on satellite position, taking account of the uncertainty introduced by the photomeasuring machine and of the present precision of the sky map. The widest possible aperture is of course desirable but f/3 is a reasonable compromise between object luminosity and construction difficulties, which leads to a 200 mm aperture for a focal length of 600 mm.

IV.2. SCIENTIFIC INSTRUMENTS

The success of a scientific satellite mission depends essentially upon the operation of the pickups and scientific instruments which make up the experimental device. If it is true that the experimental assembly is not CNES's responsibility but that of each individual experimenter, it is nevertheless necessary to make long-term provision for manufacture of special pickups adapted to space conditions. This problem of developing on-board instruments is strikingly clear in the case of special photoemissive tubes such as ultraviolet photomultipliers, picture tubes, special television tubes, etc. In another category, CNES will have to concern itself with adapting, or studying for its own applications, devices such as UHF or optical (laser) maser, within the framework of specific scientific programs.

V

DATA PROCESSING

The problems of data processing are divided into two distinct and obvious categories:

- the ground equipment,
- the on-board equipment,

The first category comprises the problem of putting the vehicle into orbit (position data processing during the guidance phase), data processing of the trajectory in order to keep the Ephemerides up to date, and lastly the exploitation or analysis of data transmitted by telemetry. Presently, CNES is not concerned with monitoring the space vehicle trajectory in real time during the propulsion phase. However, CNES has the responsibility of computing the orbit and analyzing the scientific data from the satellite: these are the two essential tasks of a future Computation Center whose construction is listed in the investment program of CNES. Insofar as possible, this Computation Center will be equipped with current devices. System studies are not considered in this report.

It is quite otherwise as far as on-board equipment is concerned; in this case everything remains to be done. Presently only the simplest processing is considered, i.e., memory storage of data for high-speed retransmission above a telemeter receiving station. For the first satellites, an analog magnetic-tape recorder seems to be the only compatible solution from the power consumption standpoint. But there is no doubt that the more ambitious vehicles thought to be launchable within a few years, can be equipped with digital memories with magnetic tape or ferrite cores, compatible with coded digital telemetry (see chapter VI). These core memories pose a delicate and quite original problem because of the mechanical environment and very low load requirements imposed by space application. Their study should be undertaken in coordination with similar programs of CNET and DGRST, but it must be kept in mind that this is a new application.

The development of a magnetic recorder can be rapidly carried out (3 years) provided it is a simple apparatus with one or two tracks, capable of recording at a low speed of 2 to 3 cm/sec, and of reading backwards at a speed of 50 cm/sec corresponding to a rate of 2500 to 5000 bits/sec. The tape length would be 200 to 300 m, or have a capacity of 1,000,000 binary units, approximately. The device would be sealed in a tight case to avoid problems of lubricants in high vacuum.

Because it is possible to introduce or read a piece of data at any point of the matrix, random access memories permit more various and more powerful operations than the simple recorder. One can think for example of certain logical operations such as comparing measurements at several reference levels, the temporary or semipermanent storage of random data or of telemetering control. Briefly, the digital memory will be one of the essential elements permitting "intelligent" operation of second generation satellites and of very deep space probes.

Ferrite core memories, extrapolated from the present computer memories, could be adapted to space quite quickly. A stacked matrix of 32,000 binary units capacity in a volume of 0.5 liter can be made with existing components (1 mm diameter cores, 600 ma control current). With 200 control transistors and associated circuitry the total volume would come to 20 liters and the power consumption to 20 watts. The objective of studies would be:

- to reduce power consumption by developing magnetic materials with lower force field,
- to withstand environmental and launch conditions,
- to develop more compact control circuits (microminiaturization, integrated circuits).

Another approach would be to take advantage of solid-state integrated circuits to make matrices composed only of high impedance elements, and therefore operating with a much lower power consumption (an essential condition for space vehicles fed by solar cells).

VI

COMMUNICATIONS AND TRACKING

The following communications systems are discussed in this chapter:

- telemetering
- remote control
- antennas

and also tracking problems which are linked to foregoing ones in the case of satellites, since very often the telemetry transmitter will be used as a radio-beacon.

For the near future there is the urgent problem of equipping the FR1 satellite and the first DIAMANT satellites. For a period of a few years and for a lightweight satellite program it therefore appears necessary to utilize:

1. the same frequency bands as NASA* for telemetry (136 Mc) and remote control (148 Mc); this choice is justified by:

    - the possibility of help from the American network for the tracking of the first satellites;
    - the known technology of omnidirectional on-board antennas,
    - the possibility of using completely transistorized on-board equipment,
    - the still reasonable amount of traffic on these frequency bands;

2. an analog data coding system derived from the AJAX (FM/FM or PEM with great excursion) telemetry;

3. a tracking system based on the listing of a simple beacon actually made up of the telemetry transmitter (carrier frequency): DOPPLER or interferometric system.

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*National Aeronautics and Space Administration.

In the case of an early congestion of the 136 Mc band this first generation equipment could easily enough be transposed to the 400 Mc band without major modifications (with the possible exception of the antennas). In the long run, however, we must prepare for far more complex missions utilizing distant satellites or space probes, requiring communications (telemetry) with great data capacity and very distant guidance capability (trajectory correction). Along these lines we have to consider:

1. higher communications frequencies: 1700 or 2300 Mc. These higher frequencies permit a much greater data capacity (wide band widths available for accurate radio positioning, since their propagation is not in practice hindered by the ionosphere). In fact, they belong to a band where radio sky noise is at a minimum, which permits use of "cold" antennas whose equivalent noise temperature does not exceed a few tens of degrees.

2. digital coding compatible with the on-board logical systems (random access digital memory), also compatible with a very large data capacity link and capable of greater transmission reliability.

3. long-range positioning devices, especially made for distance and radial velocity measurement by means of an on-board repeater.

Antennas:

The on-board antennas must be capable of telemetry and beacon (and possible repeater) signal transmission and of receiving control signals (possibly interrogation of positioning stations). In addition, in certain cases the satellite must be equipped with special antennas connected with a scientific experiment (VLF antennas for example), but this does not belong to the normal equipment to which this report is limited. The meter band omnidirectional antennas which will equip fast satellites do not pose any basic problem. It will be enough to adapt to each particular satellite outphased dipole antennas (of the turnstile type) or possibly wider bandwidth structures (of the four-leaf clover type).

The transition to decimeter waves, on the contrary, poses delicate antenna problems which should be taken care of at an early date, especially in order to equip eccentric satellites or gyroscopestabilized space probes. The following will be studied:

- omnidirectional antennas (for example a horn array),
- directive antennas with lobe of revolution,
- directive antennas with electronically switched lobes,
- parabolic antennas and automatic sighting devices.

The following types of ground antennas may be marked out:

- Static antennas, capable of very accurate goniometry. These antennas have already been the object of detailed studies and could be built immediately to equip an interference positioning device (meter waves).

- Steerable antennas. Limited gain steerable antennas will be used in the meter band to acquire telemetry signals from fast satellites. A first acceptable type is an array of four helicals permitting automatic sighting (this device is widely utilized). Another possibility is the use of four "sausage" antennas which have the following advantages over the simple helical:

  - any polarization is possible,

  - greater gain for the same size (12 db for a wavelength of 3 m at 136 Mc),

  - wide bandwidth (30 to 40%).

The theoretical study of these antennas being finished, their application to telemetry signal acquisition will be undertaken with the installation of telemetry and tracking stations (1964).

The use of decimeter waves will permit utilization of low noise ground receivers because of the very low temperature of the sky background (outside of discrete radio sources). In addition, these frequencies lend themselves well to the construction of high-gain antennas for a reasonable area. The shift to decimeter waves is therefore justified by the following, provided that very high performance antennas are used on the ground: high gain, very low temperature through elimination of the back lobes which receive ground noise. Such a "cold" antenna will probably have a large parabolic reflector (20 to 30 m diameter), steerable in all directions, and supplied by a source having a well defined lobe. A setup of the CASSEGRAIN type will certainly be considered in order to minimize the back lobes.

The study of an antenna having a performance of this kind has been started by CNET to equip the French Space Communications Station. The study of a cold antenna for the tracking of space probes will therefore be able to use their first results.

<u>Telemetry and Remote Control:</u>

In spite of certain differences in characteristics (especially bandwidth), these two types of satellite-to-ground links are based on the same technology and must progress together. We therefore consider them together in this report.

In the short term a system comparable to that utilized for the UK-1 and UK-2 satellites (Pulsed Frequency Modulation) must be built, or the AJAX system developed in France should be adapted. The following modifications would be considered:

Electronic switches:

- construction of low switching frequency, small size, low load, highly reliable switches. (It is estimated that only electronic switches can have sufficient life and reliability. Mechanical switches are excluded).

Subcarrier generators:

- complementary study of existing voltage converters to check and possibly improve their performance in satellite environmental conditions, and to reduce their power consumption.

Transmitter:

- modification of the transistorized transmitter to improve efficiency. (The order of magnitude of the necessary transmitting power is estimated at a few hundred mw for a low-altitude satellite).

- possible modification of the carrier frequency.

Receiver:

- noise factor reduction.

- MF passband reduction.

- insertion of a phase-lock discriminator.

We also have to consider long-term studies concerning wide-band telemetry. In this field the following should be undertaken:

- theoretical studies on optimum code and carrier modulation systems research;

- technical studies and construction: of switches for analog, and for conversion from analog to digital, signals; of 2000 Mc high-efficiency on-board transmitters; of cold antenna amplifiers; of PCM coders and decoders in coordination with corresponding programs started by the Armed Forces. Finally, in the very short term, it is necessary to study and construct a receiver set capable of receiving telemetry, tracking, and extracting the DOPPLER information. This receiver set would be completely transistorized except for the HF (interchangeable) front ends and would have as low a noise factor as possible (phase-lock receiver). This receiver would equip tracking and telemetry stations and its construction will be taken care of by the equipment budget of these stations.

Tracking:

Because there is a very short time before the first satellite launchings, the studies already completed for meter wave tracking station equipment must be relied upon..

Beyond this first generation tracking network (meter-wave beacon listening), it is necessary to consider now the study of a more elaborate device for distant missions. This system should operate in the decimeter wavelength to minimize sky noise. It should use ground and space vehicle directive antennas (high gain). In addition, the necessity of cooperation from the space probe is seen, since this probe will be equipped with a repeater (possibly realized by a coherent link between the remote control receiver and the telemetry transmitter). Such a system will therefore essentially measure radial velocity and will be well suited for trajectometry of bodies having quite weak apparent intrinsic motion. Its development will require detailed theoretical studies, followed by technological studies of the on-board equipment:

1. exploratory studies of long range tracking systems;

2. detailed studies with construction in mind;

3. studies and construction of a repeater system (decimeter waves).

VII

GUIDANCE AND STABILITY

Accurate space vehicle guidance during launch or orbital transfer is an essential part of a technical studies program geared to space applications.

This accurate guidance could be carried out in second-generation vehicles (the DIAMANT launcher simply follows an attitude program during the propulsion phase). The Committee does not recommend at present the development of any particular guidance system. The one studied by the Ministerial Delegation for Armament seems to be accurate enough for the missions planned by CNES for the DIAMANT satellite. Also, CNES assumes that the guidance designed for first program vehicles of the European Organization for the Development and Construction of Space Vehicle Launchers (CECLES/ELDO) will satisfy its needs. As far as a second CECLES/ELDO program is concerned, the CNES Technical Programs Committee will make proposals, if necessary, to international organizations.

Stabilization Systems Studies:

The problem of stability or attitude control of a space vehicle poses itself in a very urgent way to CNES. It is important to initiate theoretical and practical studies (prototype construction) of stabilization systems to meet the specific requirements of the scientific program. As first priority the possibility of stabilizing a DIAMANT class satellite will be studied in order to construct a solar observatory. These studies will then be extended to a variety of possible models:

- gravity gradient stabilization,
- geomagnetic field stabilization,
- earth-oriented satellite,
- star-oriented satellite (star reference).

Stability Device Components:

The components used in such systems are of a very special nature as far as mission performance requirements are concerned, as well as the size and reduced power consumption required by satellite technology. In addition, certain mechanical elements will have to operate in high vacuum, which requires bearing life studies (surface studies to avoid seizing). The following is planned as top priority:

1. a sun-tracker,
2. a star-tracker,
3. electromagnetic nozzles and valves,
4. flywheels,
5. balls and bearings,
6. miniature gyrometers,
7. study of an attitude center referred to star observations.

VIII

ENVIRONMENTAL STANDARDS AND TESTS

Far more than in any other technology, the carrying out of prolonged and severe tests is of essential importancd in space. It is obvious that the only method we have at our disposal to study the future behavior of experimental devices is to reproduce space environmental conditions in the laboratory as closely as possible. Under these conditions CNES will shortly have to install test facilities which will include:

- several small medium (10^{-6} torr) and high (10^{-9} torr) vacuum chambers,
- a large vacuum chamber with cooled walls,
- a controlled-temperature room for thermal cycling,
- a balancing machine,
- a vibrating machine,
- a centrifuge.

This equipment can be made with present technology and does not require new studies. The tests themselves are mentioned in each chapter of this report under the heading "adaption to space conditions".

The installation of test equipment does not conclusively resolve this very important question of space environment simulation. It is understood that the group in charge of environmental tests will devote some of its attention to studying the importance of laboratory tests and comparing them, as soon as possible, to the deterioration process under real flight conditions.

IX

ADVANCED MISSIONS STUDIES

This chapter concerns exploratory studies of ambitious missions whose execution can necessarily only be considered in the long term. A sufficiently detailed technical study is, however, necessary to insure that the planned mission is possible and to determine the conditions, particularly with regard to a technical improvement, which must be fulfilled in order to carry out such a mission.

The studies considered in this chapter must not be confused with the detailed satellite projects which must lead to precise equipment specifications (study comes under the satellite construction budget). In this chapter we consider exclusively preliminary studies based on computation (research department) or possibly on simulator or model experiments.

More particularly included in this chapter is study of the special problems posed by the placing of a satellite into 24-hour orbit (stationary satellite):

- the launch method from the ground or from a temporary low orbit,
- the transfer and fine corrections,
- the positioning and guidance system,
- the perturbation to a 24-hour-orbit satellite due to gravitational, electromagnetic and meteoritic effects.
- the methods for maintaining the satellite in an exactly stationary position.

X

ELECTRONIC COMPONENTS

The electronic components of industrial quality presently have a good degree of reliability. However, space applications have extreme requirements from the standpoint of performance (the highest possible efficiency, particularly) as well as from the standpoint of operational reliability under adverse conditions:

- severe stresses (acceleration, vibration) during the propulsion phase,
- ionizing radiation flux in space,
- repeated thermal cycles.

The impossibility of repairing a spacecraft must always be kept in mind. No effort should therefore be spared to obtain the highest reliability for each electronic component whose failure could cause breakdown of the system. The need for space-quality components will thus bring about profound modification of manufacturing methods, which will have to come close to the methods used in the case of submarine cable amplifiers.

In addition to this effort to increase the reliability of present standard components, space technology points up the long-run need for special components particularly characterized by good resistance to radiation, low power consumption, and, in general, microminiaturization. All the automatic manufacturing techniques which favor production of very uniform and reliable elements will be particularly attractive for space applications. It is therefore necessary to plan important studies, complementing those already started by other organizations, in order to bring about rapid advances in microminiature components technology;

- micromodules (compact assembly of micro-components in modular form),
- microcircuits made of thin films deposited in vacuum,
- solid-state integrated circuits made on a single semiconductor block by a succession of diffusions and deposits.